REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 7858	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HYDROGEN MASER FREQUENCY TRANSLATOR		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing problem.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J.J. O'Neill, D.H. Phillips, and R.R. Stone		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem R08-12 XF53-532-010K10
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Electronics Systems Command Washington, D.C. 20360		12. REPORT DATE June 27, 1975
		13. NUMBER OF PAGES 10
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Frequency translation
Frequency standard
Hydrogen maser

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A frequency translator which operates at the atomic hyperfine transition frequency of the hydrogen maser has been designed, constructed, and operated. This device, which operates in the uhf band at a frequency of about 1420 MHz, provides an output signal with a magnitude sufficient to be utilized in synthesizer or phase-locked systems. Lower frequency signals can be produced from these systems whose frequency stability is directly controlled by the hydrogen maser. Significant improvement in spectral purity can be realized through the use of this technique.

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

CONTENTS

HYDROGEN MASER FREQUENCY TRANSLATOR

INTRODUCTION

A frequency translator, derived from the Naval Research Laboratory's hydrogen maser, has been designed, constructed, and operated.* The device, which operates in the uhf band at a frequency of 1420.40575178 MHz, is configured as a classical regenerative divider; its output is a greatly amplified and highly stable submultiple (1/3) of the original input frequency. Since the output signal from the maser is extremely weak, a significant amplification is required before divider action can take place. The amplified submultiple output signal is derived solely from the hyperfine transition frequency of the hydrogen atom and is of sufficient magnitude to permit further processing with synthesizer, digital, or phase-lock techniques to produce stable frequencies from dc to uhf.

CIRCUIT DESCRIPTION

The NRL hydrogen maser frequency translator (Fig. 1) is a classical regenerative divider which has been redesigned for operation at extremely high frequency and low input level. The amplified maser signal of 1420+ MHz is applied to the rf port of a double-balanced mixer. The output, or i.f. port, of this mixer feeds an amplifier at one-third of the maser frequency, or 473+ MHz. This signal is then applied to a frequency doubler, whose output is returned to the local-oscillator input port of the mixer, thus completing the regenerative feedback path. Divider action is initiated by momentarily injecting a 473-MHz signal into the loop. The necessary loop-transfer function to sustain oscillation is obtained through the use of amplifiers, a cavity resonator, and tuned circuits.

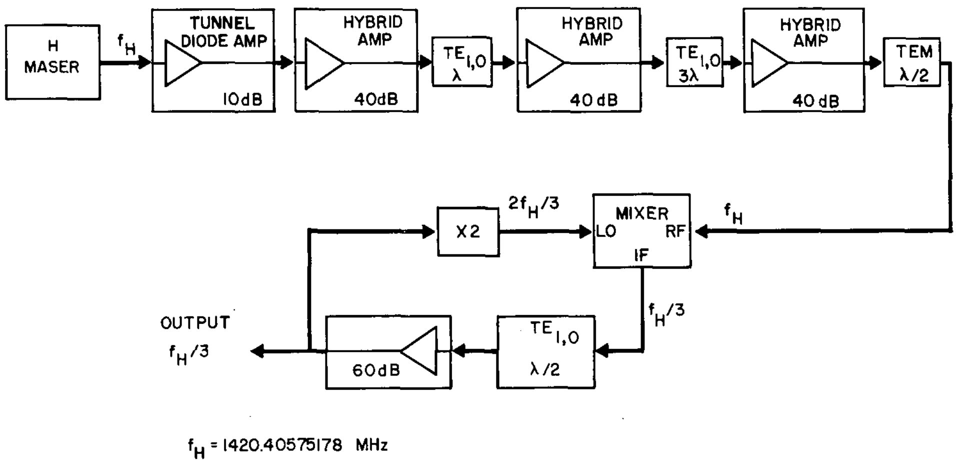

Fig. 1 — Block diagram of hydrogen maser frequency translator

---

Note: Manuscript submitted January 24, 1975.

*R. Vessot, et al., "An Intercomparison of Hydrogen and Cesium Frequency Standards," IEEE Trans. on Instrumentation and Measurement, Vol. IM-15, No. 4, pp. 165-176, Dec. 1966.

AMPLIFIER CHAIN

The principal difficulty to be overcome in effecting the translator function is that of obtaining sufficient amplification of the very weak hydrogen-maser output signal (nominally -110 dBm) without substantially degrading its signal-to-noise ratio. An amplifier chain consisting of a low-noise tunnel diode amplifier followed by three wideband thin-film hybrid amplifiers was designed for the purpose. Some of the more important parameters of these amplifiers are shown in Table 1.

Table 1
Frequency Translator Amplifier Parameters

Amplifier	Gain at 1420 MHz (dB)	Bandwidth About 1420 MHz	Noise Figure (dB)	Max. Output Level (dBm)
Tunnel diode	10	60 MHz	3.4	—41
Thin-film hybrid	40	100 MHz to 2.0 GHz	12	13

To reject the wideband noise generated by the amplifier chain, tuned cavity resonators were designed and placed following each of the wideband amplifiers. The first cavity is a TE(1, 0) mode wave guide resonator, one guide wavelength long, short-circuited at both ends. The second cavity was designed in the same manner, except that it was made three guide wavelengths long to minimize direct coupling between the input and output probes. These cavities, with Q's over 5000, have proven to be very effective in rejecting the amplified wideband noise. The final cavity, at the end of the chain, is a TEM mode cavity one-half wavelength long. Some additional parameters of these filters are listed in Table 2.

Table 2
Waveguide Cavity Resonator Parameters

Cavity Mode	Bandwidth (kHz)	Insertion Loss (dB)	Coupling
TE (1, 0)	250 kHz (Q = 5000)	2.4	Voltage probe
TEM	4.7 MHz	4	Current loop

The overall amplifier noise figure was calculated as follows:

$$F = F_1 + (F_2 - 1)/G_1 + (F_3 - 1)/G_1 G_2 + \ldots$$

where F = overall noise factor

F_i = noise factor of ith stage

G_i = power gain of ith stage

$$F = 2.2 + (16 - 1)/12.5 + (16 - 1)/12.5(10^4)$$

$$F = 2.2 + 1.2 = 3.4$$

$$F_{dB} = 10 \log_{10} F = 10 \log_{10} 3.4 = 5.3 \text{ dB}$$

Further improvements in this parameter could be made; however, the noise figure of 5.3 dB is sufficient to enable the device to function.

LOOP SELECTIVITY

The loop-transfer function necessary to sustain a stable output at the divided frequency is provided by the selectivity of the tuned cavity at the output of the mixer. A quarter-wavelength reentrant cavity with a maximum Q of 1500 was initially tried. Tests of this circuit installed in the loop produced spectra a and b of Fig. 2. The large sidebands of noise not rejected by this filter, and apparent in the figure, produced an unacceptable degradation in the stability of the output. Frequency measurements of the output made on a computing counter showed a stability of only one part in 10^4 for a ten-second averaging period.

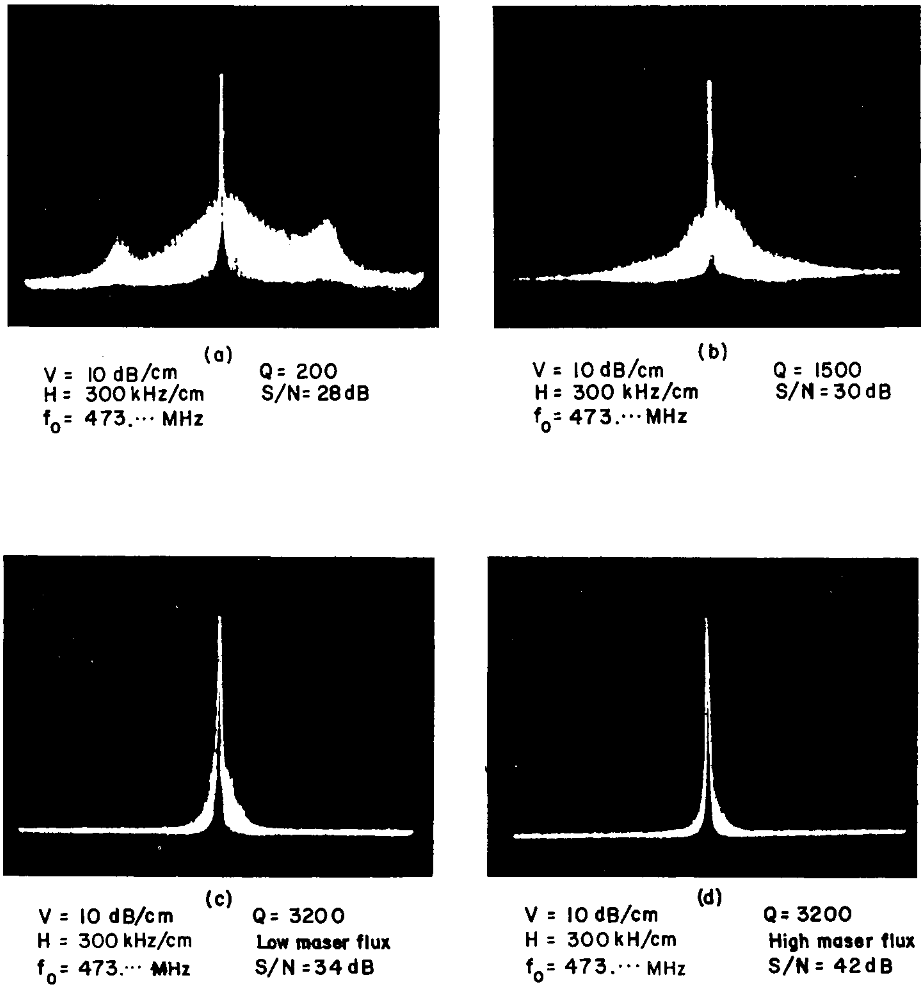

Fig. 2 — Output spectra of translator

To increase the selectivity of the loop, a TE(1, 0) mode half-wavelength resonator was designed and installed. Its Q could be varied from 3000 to 8000, depending on the insertion loss which could be tolerated. Tests with this cavity in the loop produced spectra c and d shown in Fig. 2. Figure 3 is a histogram of frequency measurements made on this output for a ten-second averaging time. Note that the standard deviation of 100 samples is 2.47 millihertz, or about 5 parts in 10^{12}. This stability is comparable with that obtained by phase locking a crystal oscillator to the maser reference.

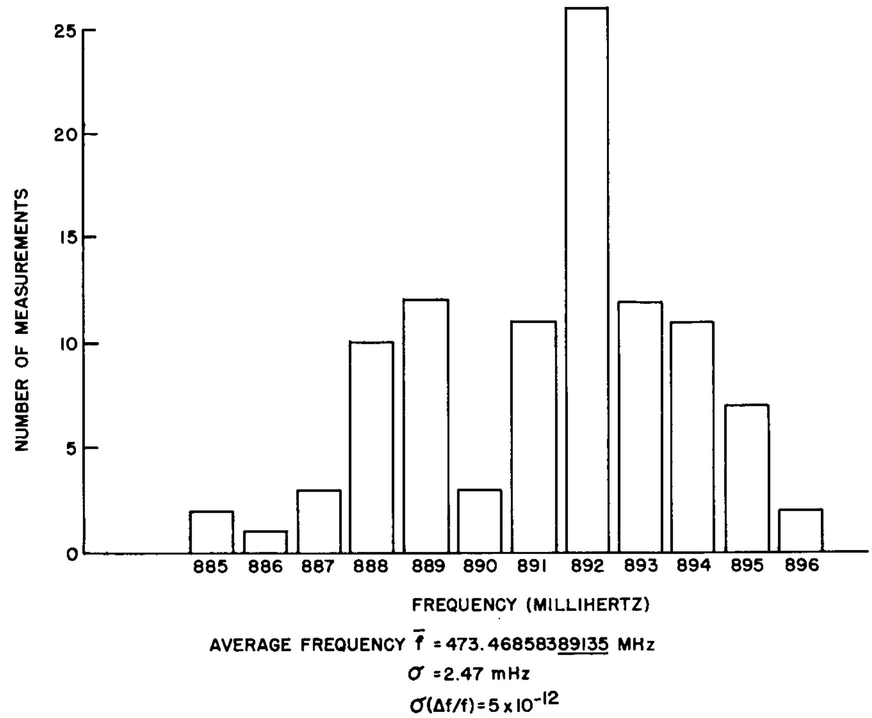

Fig. 3 — Histrogram of frequency measurements made on translator output

APPLICATONS

One application of the maser translator is shown in Fig. 4. A synthesizer driven from a quartz-crystal variable-controlled oscillator (VCXO) is employed to produce an output frequency which differs from the translator output by 500 MHz. The translator and synthesizer outputs are mixed and filtered to produce a 500-MHz output (f_x). This output is further divided (f_u) until it equals the quartz-crystal VCXO frequency. When this signal and the VCXO output signal f_0 are compared in a phase detector, a voltage is produced which can be used to complete the VCXO control loop. If Δf is the frequency deviation of the VCXO output, and if all other sources of error in the loop are assumed to be zero for purposes of analysis, then an error analysis around the loop shows that

$$\begin{aligned} mf_o &= mf_c \pm m\Delta f \\ f_x &= mf_o + f_H/3 = 500\ \text{MHz} \pm m\Delta f \\ f_u &= f_x/N = 5\ \text{MHz} \pm m\Delta f/N \\ f_o &= 5\ \text{MHz} \pm \Delta f \\ \Delta\emptyset/\Delta T &= f_o - f_u = \pm\ \Delta f(1 - m/N) \doteq \pm\ \Delta f, \end{aligned}$$

where m is the synthesizer ratio (5.306. . .); N is the divider ratio (100); f_c is the unperturbed VCXO output frequency (5 MHz); and f_H is the maser frequency (1420.40575178 MHz). This analysis shows that the rate of change of the phase-detector output is proportional to the deviation of the VCXO output.

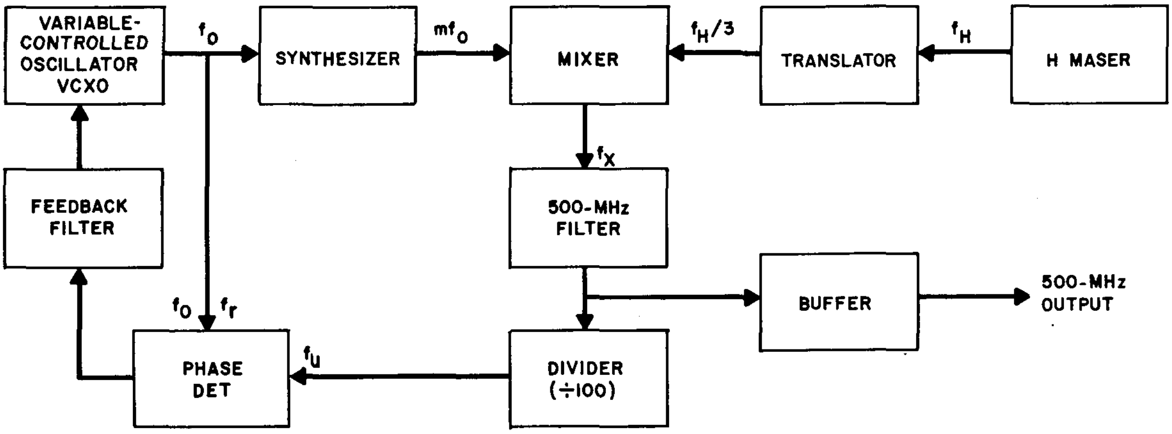

Fig. 4 — Block diagram of translator in a phase-locked loop to control the output frequency of a crystal oscillator

Figure 5 shows a conventional control loop such as is presently employed to lock a VCXO to a maser. Here an error analysis shows that

$$\begin{aligned} Mf_o &= Mf_c \pm M\Delta f \\ f_u &= Mf_o - f_H = Mf_c - f_H \pm M\Delta f \\ f_r &= mf_o = (f_c \pm \Delta f)m \\ \Delta\emptyset/\Delta T &= f_r - f_u = \pm\Delta f(M - m) = \pm M\Delta f, \end{aligned}$$

where M is the frequency-multiplication factor (284); m is the synthesizer ratio selected, such that $f_c/m = Mf_c - f_H$ (0.0811); and f_c is again the unperturbed VCXO output frequency (5 MHz). In this case, the phase-detector output is proportional to $M\Delta f$. Since M is typically 280 for this method, the translator method (Fig. 4) provides a reduction in the instability of the error signal applied to the loop filter of approximately 48 dB.

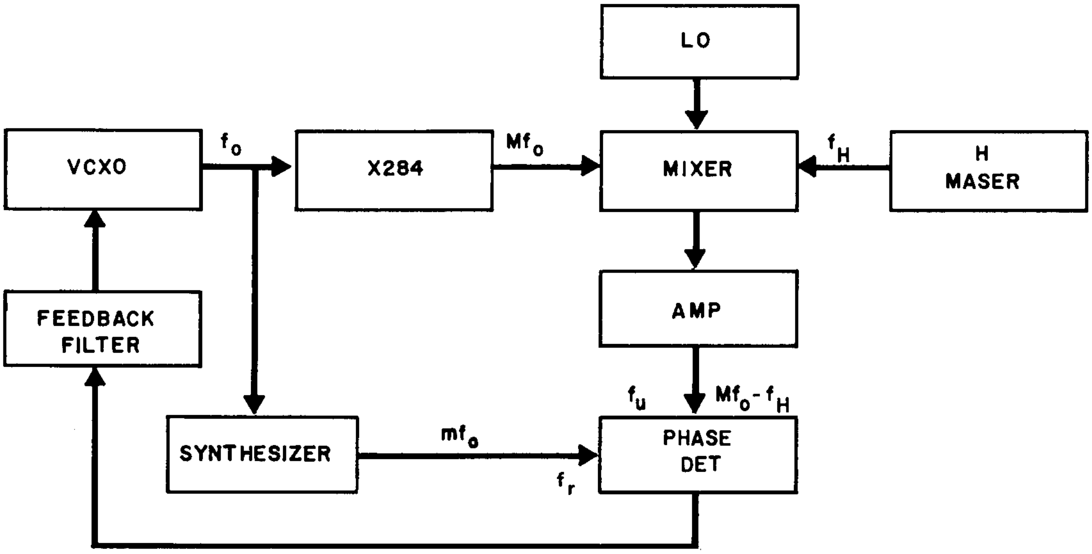

Fig. 5 — Method presently used to control the frequency of a crystal oscillator with a hydrogen maser

Some additional advantages of the translator in this circuit are: (a) no L-band local oscillator is needed, (b) no frequency multipliers are required, and (c) a high-stability uhf frequency of 500 MHz is available as a direct output.

Figure 6 shows the translator as it is assembled in the laboratory. On the left is the low-frequency cavity, which provides the selectivity for the loop. At the bottom are two of the tuned cavities in the amplifier chain of the maser signal. The two devices mounted on the left end of the top panel are the wideband thin-film amplifiers, and to the right of them are the frequency doubler and the balanced mixer. The remaining hardware consists of loop amplifiers tuned to 473 MHz and associated power supplies.

CONCLUSIONS

The use of the translator divider provides a high-frequency (473.46858389135 MHz), spectrally pure signal, generated directly from the hydrogen maser output without the necessity of a transfer oscillator. Significant improvement in spectral purity can be realized through the use of the translator technique rather than conventional oscillator multiplier techniques.

RECOMMENDATIONS

1. Development of the frequency translator should be continued to reduce the physical size of the system.

2. A direct-synthesis system should be developed to operate in conjunction with the translator, to produce outputs as required over the spectrum.

3. Developments should be conducted toward incorporating the translator function within the physical assembly of the maser.

4. Utilization techniques should be developed to produce maser-controlled, spectrally pure signals at higher microwave frequencies.

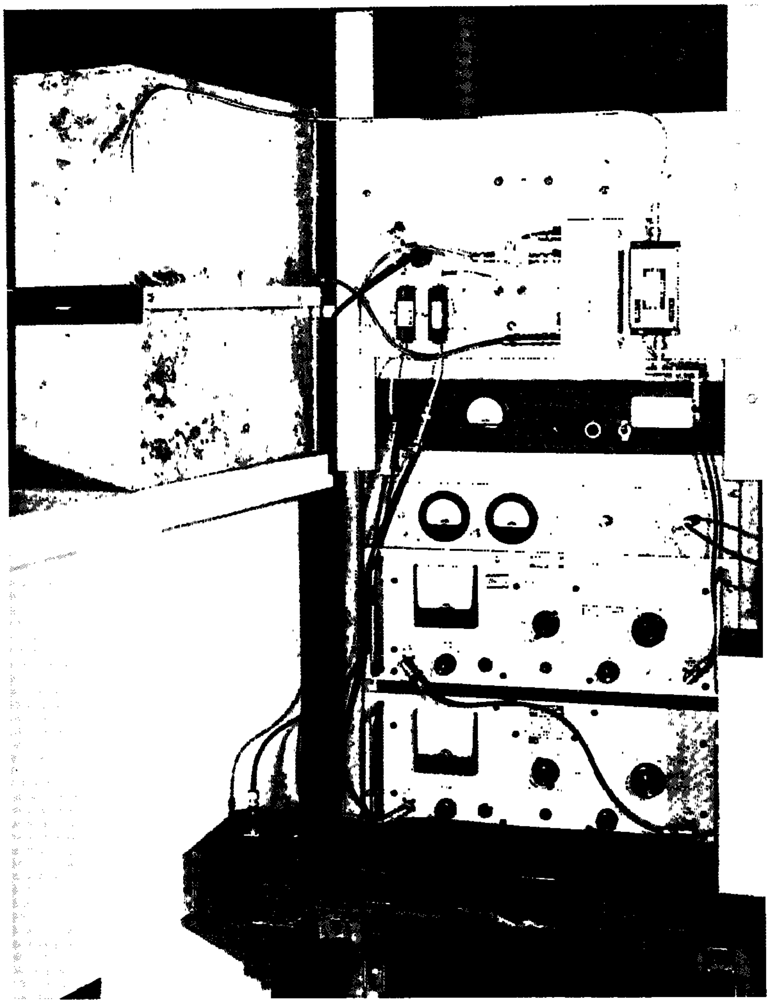

Fig. 6 — Translator assembled in laboratory

ACKNOWLEDGMENTS

The authors would like to acknowledge the support of Mr. Ted Lieberman of the Naval Electronic Systems Command and the contributions to the experiment by Mr. John Bowman and Mrs. Ruth Phillips of the Naval Research Laboratory.